S Army Corps
Engineers

AD-A239 679

(2)

WATER QUALITY RESEARCH PROGRAM

INSTRUCTION REPORT W-91-1

DESIGN AND OPERATION OF AXIAL FLOW PUMPS FOR RESERVOIR DESTRATIFICATION

by

Richard E. Punnett

DEPARTMENT OF THE ARMY
US Army Engineer District, Huntington
Huntington, West Virginia 25701-2070

July 1991

Final Report

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Monitored by Environmental and Hydraulics Laboratories
US Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
July 1991

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Design and Operation of Axial Flow Pumps for Reservoir Destratification

5. FUNDING NUMBERS

6. AUTHOR(S)
Richard E. Punnett

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USAED, Huntington, Huntington, WV 25701-2070

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers, Washington, DC 20314-1000

USAEWES, Environmental and Hydraulics Laboratories
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
Instruction Report W-91-1

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This report presents information on design considerations, construction, installation, and operation of axial flow pumps for either localized mixing or lake destratification. When used for localized mixing, the pump displaces the hypolimnetic water in the withdrawal zone of a low-level intake with epilimnetic water. When used for lake destratification, the pump moves the surface water downward to mix with the bottom water and eliminate thermal stratification. The pump consists of a frame, flotation platform, motor, gearbox, drive shaft, bearings, and a large-diameter propeller. An example of the design procedure used for destratification of Beech Fork Lake is given.

14. SUBJECT TERMS
Axial flow pump — Destratification
Beech Fork Lake — Reservoir water quality

15. NUMBER OF PAGES
34

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

PREFACE

The work reported herein was conducted as part of the Water Quality Research Program (WQRP), under the work unit "Hydraulic and Pneumatic Mixers and Aerators in Principle and Practice." The WQRP is sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE), and is assigned to the US Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation No. 96X3121, General Investigation. The WQRP is managed under the Environmental Resources Research and Assistance Programs (ERRAP), Mr. J. L. Decell, Manager. Mr. Robert C. Gunkel was Assistant Manager, ERRAP, for the WQRP. Technical Monitors during this study were Mr. David Buelow, Mr. James Gottesman, and Dr. John Bushman, HQUSACE.

The report was prepared by Dr. Richard E. Punnett, Chief of the Reservoir Control Section, Engineering Division, US Army Engineer District, Huntington, Huntington, WV. Technical review of the report was provided by Dr. James E. Garton, Professor Emeritus, Oklahoma State University.

The report was prepared under the supervision of Dr. Richard E. Price, Reservoir Water Quality Branch (RWQB), Hydraulic Structures Division (HS), Hydraulics Laboratory (HL), WES, and under the general supervision of Dr. Jeffery P. Holland, Chief, RWQB, and Mr. Glenn A. Pickering, Chief, HS. Mr. Frank A. Herrmann, Jr., was Chief, HL.

COL Larry B. Fulton, EN, was Commander and Director of WES. Technical Director was Dr. Robert W. Whalin.

This report should be cited as follows:

Punnett, Richard E. 1991. "Design and Operation of Axial Flow Pumps for Reservoir Destratification," Instruction Report W-91-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
gallons (US liquid)	3.785412	liters
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	2.54	centimeters

DESIGN AND OPERATION OF AXIAL FLOW PUMPS FOR RESERVOIR DESTRATIFICATION

PART I: INTRODUCTION

1. As lake surfaces in temperate regions warm during spring and summer, lakes become thermally stratified. The resulting stratification can dramatically affect the water quality in eutrophic lakes. Thermal stratification is not of itself undesirable; however, without the benefit of surface to bottom mixing, dissolved oxygen (DO) is often depleted in the lower layers of the lake, and the water quality deteriorates. In the absence of DO, high concentrations of hydrogen sulfide, iron, manganese, and ammonia nitrogen often persist. As temperatures moderate in the fall, the thermal differences in the lake are reduced, and the lake eventually becomes isothermal (destratified). When isothermal conditions exist, the lake water quality parameters are improved as the lake naturally mixes and DO is increased throughout the water column.

2. Lake destratification by man-made means has been demonstrated to be effective in improving water quality (Quintero and Garton 1973; Steichen, Garton, and Rice 1974; Strecher 1976; Punnett 1978, 1988; Garton and Punnett 1980; Robinson, Garton, and Punnett 1982; Price and Sneed 1989). The two principal methods of mixing to cause destratification are diffused-air pumping and mechanical pumping. Diffused-air pumping is used for direct aeration of the bottom waters and for inducing lake mixing by entraining bottom waters in the rising bubbles. Mechanical pumping may be performed to pump the oxygen-rich surface waters downward to mix with the lower lake levels. Both methods can be used for either localized or whole lake destratification. Localized destratification by mechanical mixing can be used to improve the outflow water quality from a lake by displacing the bottom waters with surface water in the vicinity of the intake structure, which withdraws predominantly from the hypolimnion (Givens 1978; Moon, McLaughlin, and Moretti 1979; Busnaina, Lilley, and Moretti 1981; Robinson, Garton, and Punnett 1982; Price and Sneed 1989). Laboratory tests indicated that a maximum of about 80 percent surface water pumped downward can be released downstream from a bottom intake using localized mixing.

3. For a particular application, the best method can be selected after

evaluating the following considerations: cost, operation and maintenance, lake depth, degree of stratification, and areal extent of destratification. Mechanical pumping systems are often cheaper than diffused-air pumping systems. Mechanical pumping is generally inexpensive in daily operation and can be easily maintained. However, mechanical pumping is often not feasible in deep lakes that have a strong stratification pattern because of buoyant forces that inhibit the downward penetration of the lighter surface water.

4. A specific type of mechanical pump that has been applied successfully to mechanical pumping is the axial flow pump, often referred to as the Garton pump. The axial flow pump consists basically of a frame, flotation platform, motor, gearbox, drive shaft, and propeller (Figure 1). The pump is designed for moving large volumes of water with a low power input. A propeller, such as a cooling tower fan (Figure 2), is suspended below the water surface and rotated to pump surface water downward. Even though a low-head, low-velocity jet is produced, the large-diameter propellers (up to 5.2 m) pump a large volume of water (up to 4.5 m^3/sec). The design of such a system is discussed in the next section.

Figure 1. Garton pump

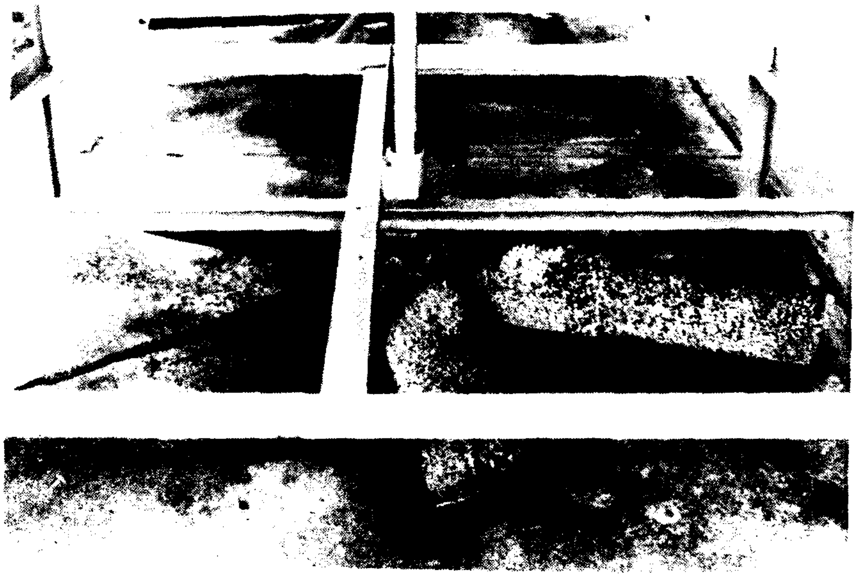

Figure 2. Pump propeller

PART II: DESIGN OF AXIAL FLOW PUMPS

Theory of Design

5. As surface water is pumped downward into the hypolimnion, a plume of warm (light-density) water is formed within the lower layers of cold (heavy-density) water. Buoyant forces acting upon the plume impede the downward velocity of the plume until a relatively stable mixing depth is established. The plume must penetrate to the desired depth in order to be effective. The desired depth would be the lake bottom if lake destratification is the objective or to the intake invert if localized destratification is the objective. Several equations have been developed by Punnett to predict the depth of plume penetration for axial flow pumps (Punnett 1984), the best nondimensional form of which is

$$\frac{H_p}{D} = 0.176 \frac{V^2}{g(\Delta\rho/\rho_o)} + 0.756 \frac{H_e}{D} \tag{1}$$

where

H_p = length of plume, m

D = pump diameter, m

V = initial jet velocity, m/sec

g = gravitational constant (9.81 m/sec^2)

$\Delta\rho$ = difference in density between surface and desired depth of penetration, kg/m^3

ρ_o = average density of pumped water

H_e = length from pump to thermocline, m

6. In Equation 1, the first term on the right side accounts for plume penetration into dissimilar density strata. The second term on the right side accounts for penetration within the epilimnion where little buoyant resistance is encountered. The depth of the thermocline (for the above equation) was considered to be from the pump propeller to the depth at which the first major increase in density (or temperature) occurred. In a case where no apparent thermocline exists but there is a thermal gradient, the midpoint between the pump and the desired depth of penetration should be used. Other predictive equations have been developed (Holland 1984, Punnett 1984) for surface pumps;

however, Equation 1 was derived from field tests specifically designed to determine the best penetration equation for axial flow pumps.

7. The values for density can be obtained from a lake temperature profile and water density tables. In the absence of chemical-density gradients, the density of water (ρ , in kilograms per cubic meter) can be calculated using Equation 2 (Ford 1983), and the average density of pumped water (ρ_o) can be calculated using Equation 3:

$$\rho = 1{,}000 - \frac{(T - 3.98)^2 (T + 283)}{(503.57)(T + 67.26)} \tag{2}$$

where T is the temperature of water (°C),

and

$$\rho_o = \frac{(\rho_s + \rho_1 + \rho_2)}{3} \tag{3}$$

where

ρ_s = density of water at the surface

ρ_1 = density of water at 1 m below the surface

ρ_2 = density of water at 2 m below the surface

8. Early work (Robinson, Garton, and Punnett 1982; Steichen, Garton, and Rice 1974) concluded that the following fan laws provide an effective means of predicting the pump performance in water from the available data based on air tests for a constant diameter:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \tag{4}$$

$$\frac{P_1}{P_2} = \frac{N_1^3 \rho_1}{N_2^3 \rho_2} \tag{5}$$

where

Q = pump flow rate

N = rotative speed, rpm

P = blade input power, kw

Note:

1 = air

2 = water

$$\frac{\rho_1}{\rho_2} \approx 1.22 \times 10^{-3}$$

9. Using Equations 4 and 5 and a manufacturer's propeller performance curve developed for a specific propeller in air, the performance in water can be determined. The power in Equation 5 represents the power required by the propeller; motor sizing should also include calculations of power losses in the bearings and gearbox. An example application of the above equations is given in Appendix A.

Sizing of Pumps

10. For use as a design factor, Equation 1 can be used to solve for the design velocity assuming a pump diameter. For large-diameter propellers normally manufactured for operation in air, the maximum design velocity should be less than about 1.0 m/sec because the propeller hub is designed for stresses related to high-speed, low-resistance operation. A good target velocity is about 0.5 to 0.8 m/sec. A propeller designed for operating in water, such as a ship's propeller, can be operated at higher velocities than the target velocity.

11. The pump diameter and number of pumps required are determined by considering the flow rate needed to be pumped. The flow rate (Q , in meters per second) is calculated by

$$Q = 0.785D^2V \tag{6}$$

12. Because the pump velocity has important design limitations, and because only discrete pump diameters are available, there is no

straightforward approach to solving for the velocity and diameter simultaneously. However, an iterative process will quickly lead to a solution. Propeller diameters of 1.22, 1.83, and 2.44 m are generally available from manufacturers of cooling tower fans. Assuming a propeller diameter and using Equation 1 to determine the required velocity, Equation 6 can then be used to determine the flow rate. If the required flow rate is greater than what the 2.44-m pump will yield, multiple pumps generally will be required. Use of multiple pumps also allows for more operating options and, if required, permits pump maintenance without complete shutdown. Aircraft propellers have been used for pumps having a propeller diameter of 5.2 m.

13. If localized destratification is desired for the purpose of improving the outflow water quality, the pumping flow rate is a critical design parameter as well as the depth of penetration. Too little flow will not produce the desired results; too much flow may cause a greater mixing action, which can give less than maximum benefits. Some site-specific tests have shown that the maximum benefit is achieved by pumping about half of the release rate (Robinson, Garton, and Punnett 1982).

14. If lake destratification is desired, an evaluation of the required flow rate is difficult. Factors such as wind action, basin morphometry, size and shape of the lake, volume of hypolimnion, degree of stratification, time of year, and pump location have major influences on the required pumping rate. The pumping rate in early summer is much greater than that required in late summer because the larger influx of heat attempts to restratify the impoundment. As pumping occurs, the warm water being forced downward mixes with the cold bottom waters. The mixed water, which has an intermediate temperature and density, rises to the depth of approximately the thermocline (or to a depth of equal density). As pumping continues, the zone of mixed water spreads horizontally and begins to widen vertically in a "lens" fashion. The rate of spreading may be limited by the pumping rate or by the hydrodynamic and buoyant forces associated with mixing water of dissimilar densities. Pumping a flow rate that is too low will limit the amount of water available for mixing. Pumping a flow rate that is too high may set up a recirculating cell around the pump, resulting in excess operating costs. Ideally, the pumping rate would equal the maximum rate at which the mixed buoyant pumping plume would spread throughout the lake.

15. In Ham's Lake (40 ha, surface), Oklahoma, a 1.83-m-diam pump

completely destratified the lake within a 1-week period (Quintero and Garton 1973; Steichen, Garton, and Rice 1974; Strecher 1976). The 1.1-kW pump was placed near the middle of the lake, and its flow rate was about equal to pumping the volume of the hypolimnion once every 4 days. However, successful destratification was achieved using smaller pumps that pumped the volume of the hypolimnion once every 8 days. In Beech Fork Lake (291 ha), West Virginia, the same ratio (volume of the hypolimnion pumped in 8 days) of pumping did not have the same success (Punnett 1988). Beech Fork Lake has a bifurcated shape, and the pumps were placed within 30 m of the dam. Unlike the Ham's Lake project, the pumps were not located in the middle of Beech Fork Lake, which meant the mixed lens of water could not spread in a full radial fashion. Unpublished observations by the author indicate that the pumping rate was too great for the rate at which the mixed water would spread throughout the lake; thus, much of the pumped water was being recirculated in a localized cell around the pumps. Although Beech Fork Lake was not completely destratified until the heat input moderated in late August, the thermocline was lowered throughout the lake and the temperature difference within the lake was reduced to about 3° C for most of the summer.

PART III: CONSTRUCTION

Generalized Parts and Construction

16. The construction of an axial flow pump requires only basic shop functions, but machining of the drive shaft ends is sometimes required. The pumps can be constructed using a welded metal frame, flotation platform, motor, right-angle gearbox, drive shaft with couplings, bearings, and a propeller. The axial flow pump has been constructed in-house as well as commercially. Many pumps have been constructed by college students in a university shop. From a generalized parts list and a hand sketch, a machine shop in Point Pleasant, WV, constructed the main components for four axial flow pumps (1.83-m-diam with a single hermetic steel tank for flotation) for about $24,000 in 1986 (Figures 3-5). The pump sizing calculations, actual design specifications, generalized parts list, and sketch used by the machine shop are given in Appendix A. E. C. Baker & Sons, Inc., Sigel, IL, markets axial flow pumps that are completely equipped for about $11,000; delivery and installation are available at additional cost.

17. The flotation platform can be made either with foam blocks or with hermetic containers. If hermetic containers are used, some flotation material should be put inside, in case the containers develop a leak. After estimating the weight of the pump, the platform should be designed to float the pump with

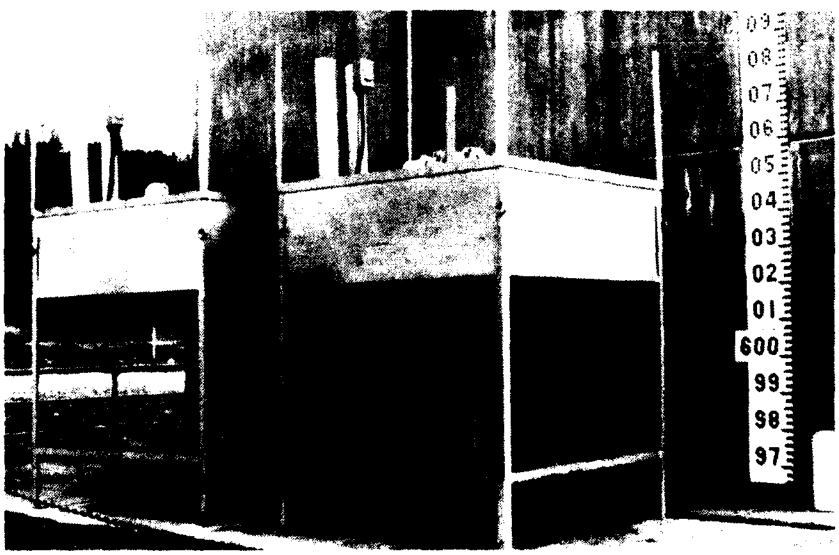

Figure 3. Two assembled pumps

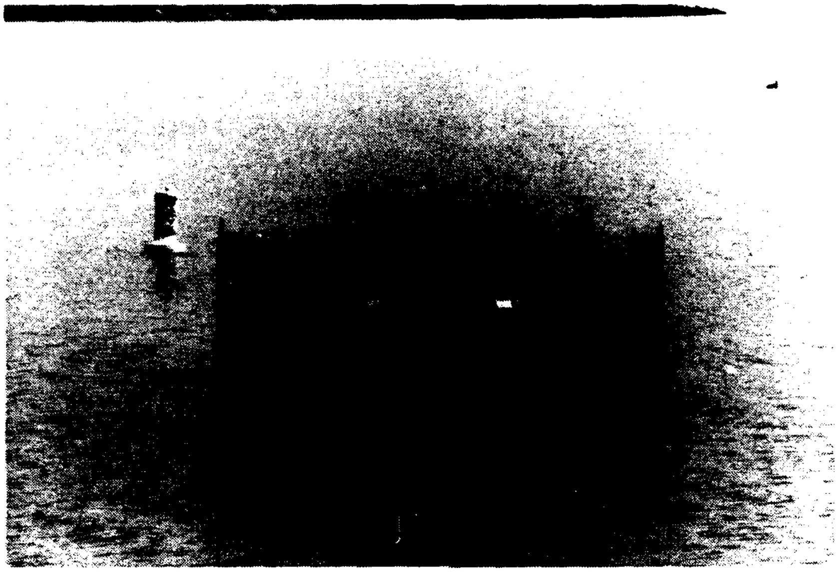

Figure 4. Two pumps in operation

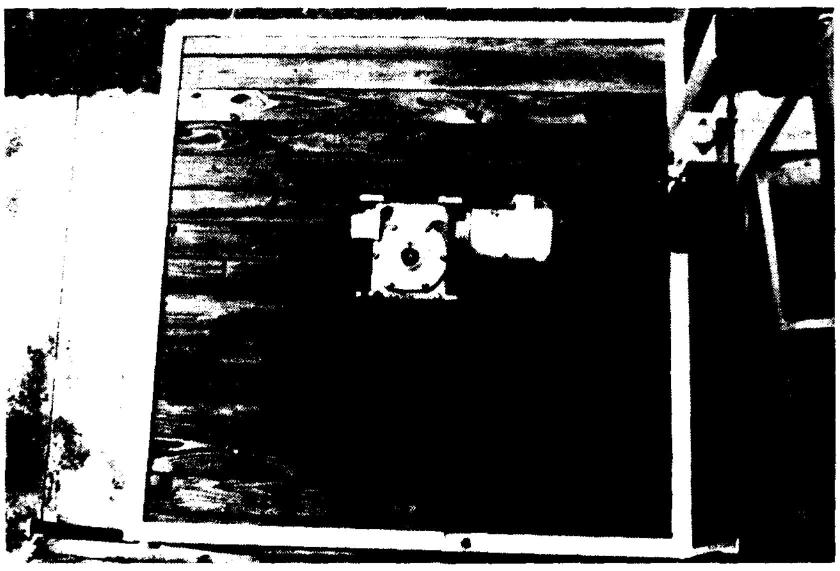

Figure 5. Pump gearbox, motor, and switch

about 0.5 m freeboard. If flotation blocks are used, protection from waterfowl may be necessary.

Drive Train

18. Both diesel and gasoline engines have been used to power the pumps where electrical connections were not feasible; however, electrical motors are much easier to operate. The use of fuel not only dramatically increases operational expenses and hardships, but can deteriorate some flotation materials and create environmental concerns.

19. If an electric motor is used, the electrical connections consist of individual switch boxes for each motor as well as a central starter switch station for a cluster of pumps. The motor selection should include adverse-environment casing (specified TEFC, total enclosed fan cooled) and be consistent with the available power source. In case of power failure, a manual starter switch can prevent multiple pumps from automatically starting simultaneously. Delay circuits are available which allow the pumps to restart sequentially, thus avoiding a possible overloading of the power lines. Generally, the power line runs from the source onshore, along the lake bottom, and up to the pumps.

20. The gearbox should be designed for continuous operation under adverse environmental conditions. A high-quality, heat-resistant gear oil should be used. The reduction ratio of the gearbox is dependent upon the input speed of the motor and the required drive shaft speed of the propeller. The gearbox should be mounted on an elevated frame above the platform surface so that the coupling joining the drive shaft is serviceable from the top of the flotation platform. This is a critical consideration if a gearbox requires replacement while the pump is anchored in the lake.

21. A suitable drive shaft material is cold-rolled steel. Stainless steel shafts are unnecessarily expensive. A stress analysis should be made to determine the necessary diameter. A 3.8-cm-diam shaft has been used successfully for a 1.83-m propeller, and a 5.1-cm-diam shaft has been used successfully for a 2.44-m propeller. The shaft length should allow the propeller to be suspended about 1.5 to 2.0 m below the water surface for propellers less than 2.5 m. The ends of the shaft may require machining to attach the coupler and propeller. Key slots are often required. If a rigid coupler is used, the

gearbox can generally handle both the weight of a suspended propeller and the upward thrust forces when operating. If a flexible coupling is used, shaft bearings (or bushings) will need to handle the vertical forces as well as stabilize the shaft horizontally.

22. The actual blade configuration (shape and number) of the propeller seems to be of little consequence to the penetration performance of the pump. Aerovent, Inc., Piqua, OH, manufactures six-bladed cooling tower fans that perform well as propellers for an axial flow pump (Figure 2). The propeller pitch is adjustable so that the flow rate can be set for a given rate of rotation. The blades are also reversible. Care should be given to ensure a proper blade setting; the blade angle should be greater at the hub than at the blade tips. An improperly installed blade produces unpredictable pumping results. A propeller shroud, designed to improve pumping efficiency by guiding the flow and reducing entrance losses, is optional.

23. Once all the material and parts are gathered, approximately 80 man-hours (engineer and/or technician) is required for construction of the major components. If a pump is built on contract and is no greater than 2.44 m wide (highway limitation), the major components should be assembled by the contractor and delivered as a complete unit. If a pump is larger than 2.44 m, delivery of the components and site assembly may be best.

24. Where public access could be a problem, fences have been installed around the flotation platform. To prevent debris from entering the propellers, fencing has been installed below the flotation platform. Warning signs, indicating high voltage, have been used. Yellow flashing lights have been installed where a potential nighttime boating hazard existed. High-performance epoxy base paints have been successful in preventing corrosion of metal parts. Wheels have been installed on some pumps to facilitate loading from a boat launch area.

PART IV: INSTALLATION

Launching and Site Location

25. With the possible exception of fencing, the pumps should be complete and ready for operation before installation since most tasks are more difficult while the pumps are floating. The most efficient method of installation is to place the assembled pump in the lake using a crane. If wheels have been installed on the base of the pump frame, a cable to control the rate of descent down the ramp should be attached as low as possible on the frame (near the wheels). Because of the deep draft of the pump, the ramp depth should be checked for suitability. Loading from a boat launch area will require personnel who are ready and able to skin dive. After a pump is in the lake, it can be easily pushed by a small boat (in barge fashion) to the pumping site. Generally, three people are able to install one pump in about 2 hr.

26. The location of the pump site is an important issue that involves not only lake mixing considerations, but also common logistics such as the availability of power, potential boating hazards, likelihood of vandalism, and access for maintenance. The best location, for lake mixing concerns only, is over the deepest site that is centrally located. In lakes with extensive dendritic patterns or where the hypolimnion may be partitioned by submerged topography, several locations may need to be evaluated. For localized mixing, the pump should be placed just upstream of the intake port. Pump location and configuration (Price and Sneed 1989) for a three-pump, localized destratification operation at J. Percy Priest Reservoir indicated the location in front of the intake can have a significant influence on system efficiency.

Anchoring

27. Generally, pumps are anchored in position, but some have been secured to an existing structure. The two main concerns are the ability to accommodate changes in surface elevations and to compensate for induced torque. In the case of anchoring, some slack should be left in the anchor lines to accommodate expected lake rises. The torque induced by the turning propeller will cause slack lines to partially wrap around the pump (or cluster of pumps) until all lines are taut. This is a useful side effect since the

pump(s) will "unwind" as the lake level increases and "rewind" as the lake lowers, thereby maintaining position. In the Beech Fork application (Punnett 1988), a cluster of four 1.83-m-diam pumps was held in position by four anchors and 0.635-cm steel cables. The anchors were made by cutting 55-gal* drums in half and filling with concrete. A short piece of heavy-gauge chain was set in the concrete so that the cable was easily attached. The anchors were positioned off the corners of the square cluster of pumps far enough away so that the taut cables formed a 45-deg angle with the lake surface.

28. The total weight of the anchors should not exceed the floating capacity of the platform in case of extreme lake rises. If it appears that the anchors may be lifted because of an imminent extreme rise, the pump(s) should be shut off. An auxiliary anchor with a longer cable could hold the pumps near the site if it is important to maintain the relative position.

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

PART V: OPERATION AND MAINTENANCE

29. For localized destratification, the pumping activity should commence with declining water quality conditions in the lower strata of the lake and coincide with the release schedule. One of the benefits of localized mixing is that the pumps need only to be operated during a period of hypolimnetic releases (e.g., hydropower generation or summer flood control).

30. For lake destratification programs, significant stratification can be prevented in lakes if pumping begins early, thereby possibly avoiding anoxic conditions in the hypolimnion. In the late spring and early summer, the lake surface temperatures may increase rapidly, and the full pumping capacity should be used. Although the system is designed to pump the volume of the hypolimnion in a given time, full pumping capacity is not needed until the maximum heat loading to the lake occurs. If start-up of the system is delayed or solar input is much more than design condition, complete destratification may not be achieved.

31. The effect of pumping is to warm bottom waters to surface temperatures. There may be a slight cooling of surface temperature, but it does not appear to be significant. As the heat input moderates (about mid-August), only a minimal amount of pumping is required to maintain isothermal conditions. The pumping schedule depends primarily upon weather conditions. By early September, pumping may not be needed even though the lake would normally stay stratified until November.

32. The success of the pumping effort can be easily determined using temperature and DO profiles. Profiles of temperature and DO, taken immediately beside the pump(s), will reveal whether the pump jet is penetrating to the proper depth. The temperature in the pumped plume will be relatively constant (at surface values) until the depth of penetration is reached. At that point, readings become erratic; readings below the penetration depth become stable at a colder temperature. Changes in release water temperature and DO, as monitored downstream, will quickly indicate the success of a localized pumping effort.

33. In the case of whole lake destratification where pumping begins early (e.g., April), weekly profiles are usually sufficient for monitoring progress. If pumping commences after stratification has been established, profiling every other day would be important until nearly isothermal

conditions prevail; then, weekly profiles become sufficient. To identify all the changes caused by lake destratification, an expensive and intensive program is needed; however, to assess the success of the pumping effort, temperature and DO are usually sufficient indicators. A program to identify all changes would include a study, both inlake and downstream, of benthos, plankton, chemistry, and fish.

34. For localized destratification, three sampling stations may be sufficient to monitor the pumping program: one station upstream of the dam to monitor lake profile conditions, one station within the pump plume, and one station immediately downstream of the dam. For lake destratification, several stations should be considered in addition to those identified for localized destratification. The shape and bottom contour of the lake are important considerations in determining sampling station locations. Stations located in the thalweg will usually give the best indication of destratification success.

35. Maintenance needs of the axial flow pump, with an electric motor, are relatively minor. An axial flow pump driven by a fuel engine will be essentially as reliable as the engine. The gearbox requires an occasional oil-level check, about every 2 months of operation. An oil change after a specified operation time, such as once a year under continuous operation, is recommended. The gear oil should be of high quality and heat resistant; in some cases, oils have "baked" and allowed gear failure. In gearboxes, a brass gear might require replacement if worn excessively. The gears should be checked at least once a year. Pumps have been left in the water for 3 years without problems. A good maintenance plan would require pump removal every other year for inspection, cleaning, and repainting. The expected useful life of a pump with proper maintenance would be limited by the life of the gear box and motor, assuming rust problems do not develop. Based on previous destratification projects, 5 to 10 years of operation can be anticipated. If fencing was used below the water surface, replacement of the fencing each year may be necessary due to corrosion. If a pump is removed from the lake for winter storage, the anchor cables can be attached to a single buoy and left in place.

PART VI: SUMMARY

36. This report discusses design and construction methods for axial flow pumps used for localized mixing and lake destratification. The theory of design along with computation procedures for sizing of pumps is given. Construction methods, including materials and parts, are discussed. The propellers used in the design are cooling tower fans with variable pitch to achieve a desired flow rate. Installation information includes location of the pumps on the reservoir and anchoring techniques. A section on operation and maintenance gives techniques for monitoring the success of a localized mixing or lake destratification project. Maintenance needs, although minimal, are based on operation of the pump during the stratified season. The design computations used for construction of the Beech Fork Lake destratification system are given in Appendix A. Specifications for axial flow pumps are presented in Appendix B.

REFERENCES

Busnaina, A. A., Lilley, D. G., and Moretti, P. M. 1981. "Prediction of Local Destratification of Lakes," Journal of the Hydraulics Division, ASCE, Vol 107, No. HY3.

Ford, D. E. 1983. "An Assessment of Reservoir Density Currents and Inflow Processes," Technical Report E-83-7, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Garton, J. E., and Punnett, R. E. 1980 (May). "Quality Improvement of Releases from Reservoirs," Proceedings, Surface Water Impoundments Symposium, Minneapolis, MN, Paper No. 5-7.

Givens, M. R. 1978. "Hydraulic Modeling of Local Destratification of Lakes Using Propeller Pumps," M. S. thesis, Oklahoma State University, Stillwater, OK.

Holland, J. P. 1984. "Parametric Investigation of Localized Mixing in Reservoirs," Technical Report E-84-7, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Moon, J. J., McLaughlin, D. K., and Moretti, P. M. 1979 (Sept). "Enhancement of Reservoir Release Water Quality by Localized Mixing," Final Report, Phase 1, Contract DACW39-78-C-0045, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Price, R. E., and Sneed, R. B. 1989 (Aug). "Localized Mixing for Improvement of Reservoir Releases from J. Percy Priest Reservoir," Proceedings, ASCE Conference on Hydraulic Engineering, New Orleans, LA.

Punnett, R. E. 1978 (Jul). "Destratification of Lake Arbuckle with a Cluster of Low Energy Pumps," M. S. thesis, Oklahoma State University, Stillwater, OK.

__________. 1984 (Dec). "Predicting the Depth of Penetration of a Buoyant Plume in a Stratified Lake," Ph. D. thesis, Oklahoma State University, Stillwater, OK.

__________. 1988. "Destratification of Beech Fork Lake," Proceedings, Water Quality '88 Seminar, Charleston, South Carolina, US Army Corps of Engineers, Committee on Water Quality, Washington, DC.

Quintero, J. E., and Garton, J. E. 1973. "A Low Energy Lake Destratifier," Transactions, American Society of Agricultural Engineers, Vol 16, No. 5.

Robinson, K. M., Garton, J. E., and Punnett, R. E. 1982. "Localized Destratification at Lake Texoma," Journal of the Environmental Engineering Division, ASCE, Vol 108, No. EE4.

Steichen, J. M., Garton, J. E., and Rice, C. E. 1974. "The Effect of Lake Destratification on Water Quality Parameters," Paper No. 74-5008, American Society of Agricultural Engineers, St. Joseph, MI.

Strecher, R. G. 1976. "Design, Construction, and Evaluation of a Prototype Low-Energy Lake Destratifier," M. S. thesis, Oklahoma State University, Stillwater, OK.

APPENDIX A: BEECH FORK LAKE PUMP DESIGN

Introduction

1. Beech Fork Lake is located on a tributary of Twelvepole Creek in northwestern West Virginia. This 750-acre lake, with a maximum depth of 35 ft, is used for recreation and fish and wildlife enhancement. Thermal stratification during the summer results in a shallow epilimnion (about 2 m) and anoxic conditions in the hypolimnion. This limits habitat available to the fishery, as well as biological productivity. To increase the habitat available to the fishery, a destratification project was initiated in 1987.

Destratification Objective

2. The major objective of the destratification was to increase the depth of the epilimnion and thereby increase the available habitat for the fishery. This was accomplished using four Garton-type pumps to mix the lake. These pumps were operated to pump epilimnetic water through the thermocline into the hypolimnion. The epilimnetic water mixed with the hypolimnetic water to produce a volume of water with a temperature near the thermocline temperature. Thus, the mixed water moved throughout the lake as a layer in the thermocline region. As pumping continued, this layer increased in length and thickness until both the warm and cold water were mixed and the lake was isothermal.

Pump Design

3. The design of the Garton pumps was accomplished using the design equations and guidance provided in the main text. Pertinent data from Beech Fork Lake are given in Table A1.

Table A1

Pertinent Data, Beech Fork Lake, West Virginia

Parameter	Value
Surface area	293 ha
Maximum depth	10.7 m
Extreme thermal conditions	
Surface	24° C
1 m below surface	22° C
2 m below surface	21° C
10.7 m (bottom)	14° C
Minimum depth to top of thermocline	2.1 m
Volume of anoxic hypolimnion	6.0×10^6 m^3

4. Using Equations 2 and 3 of the main text, the densities associated with the thermal stratification are

$$\rho_{24} = 997.3 \text{ kg/m}^3$$
$$\rho_{22} = 997.8 \text{ kg/m}^3$$
$$\rho_{21} = 998.0 \text{ kg/m}^3$$
$$\rho_{14} = 999.3 \text{ kg/m}^3$$

$$\rho_o = \frac{(997.3 + 997.8 + 998.0)}{3} = 997.7 \text{ kg/m}^3$$

$$\frac{\Delta\rho}{\rho_o} = \frac{(999.3 - 997.7)}{997.7} = 0.0016$$

5. For whole lake destratification, the pump plume should penetrate to the lake bottom at the pump site. Assuming a propeller diameter of 1.83 m, Equation 1 is solved for the velocity:

$$\frac{10.7 \text{ m}}{1.83 \text{ m}} = \frac{0.176V^2}{9.81(0.0016)} + \frac{0.756(2.1 \text{ m})}{1.83 \text{ m}}$$

Therefore,

$$V = 0.67 \text{ m/sec}$$

6. Using Equation 6 to find the associated flow rate yields

$$Q = 0.785\ (1.83)^2\ (0.67) = 1.76 \text{ m}^3\text{/sec}$$

From the manufacturer's propeller performance curve (as shown in Figure A1), for a 6-ft-diam propeller having six reversible blades, a blade pitch of 22 deg, and a rotation rate of 50 rpm, the flow rate is about 3,600 cfm at a low head (static pressure). After conversion, the flow rate is about 1.70 m^3/sec. For this project, an electric motor with an input rotation rate of about 1,750 rpm was used. To produce 50-rpm output to generate 1.70 m^3/sec of flow, a gear ratio of 35:1 would be needed. Since a gearbox with a ratio of 50:1 was readily available, the adjusted propeller performance was calculated.

7. Using Equation 4 to determine the flow rate for the same propeller at 35 rpm yields

$$\frac{1.70 \text{ m}^3\text{/sec}}{Q_2} = \frac{50 \text{ rpm}}{35 \text{ rpm}}$$

therefore

$$Q_2 = 1.19 \text{ m}^3\text{/sec}$$

8. The blade power requirement is computed (assuming the density ratio of air to water is 1.22×10^{-3}), using the manufacturer's propeller performance curve (Figure A1) and Equation 5:

$$\frac{0.0015 \text{ hp}}{P_2} = \frac{(50 \text{ rpm})^3}{(35 \text{ rpm})^3}\ 1.22 \times 10^{-3}$$

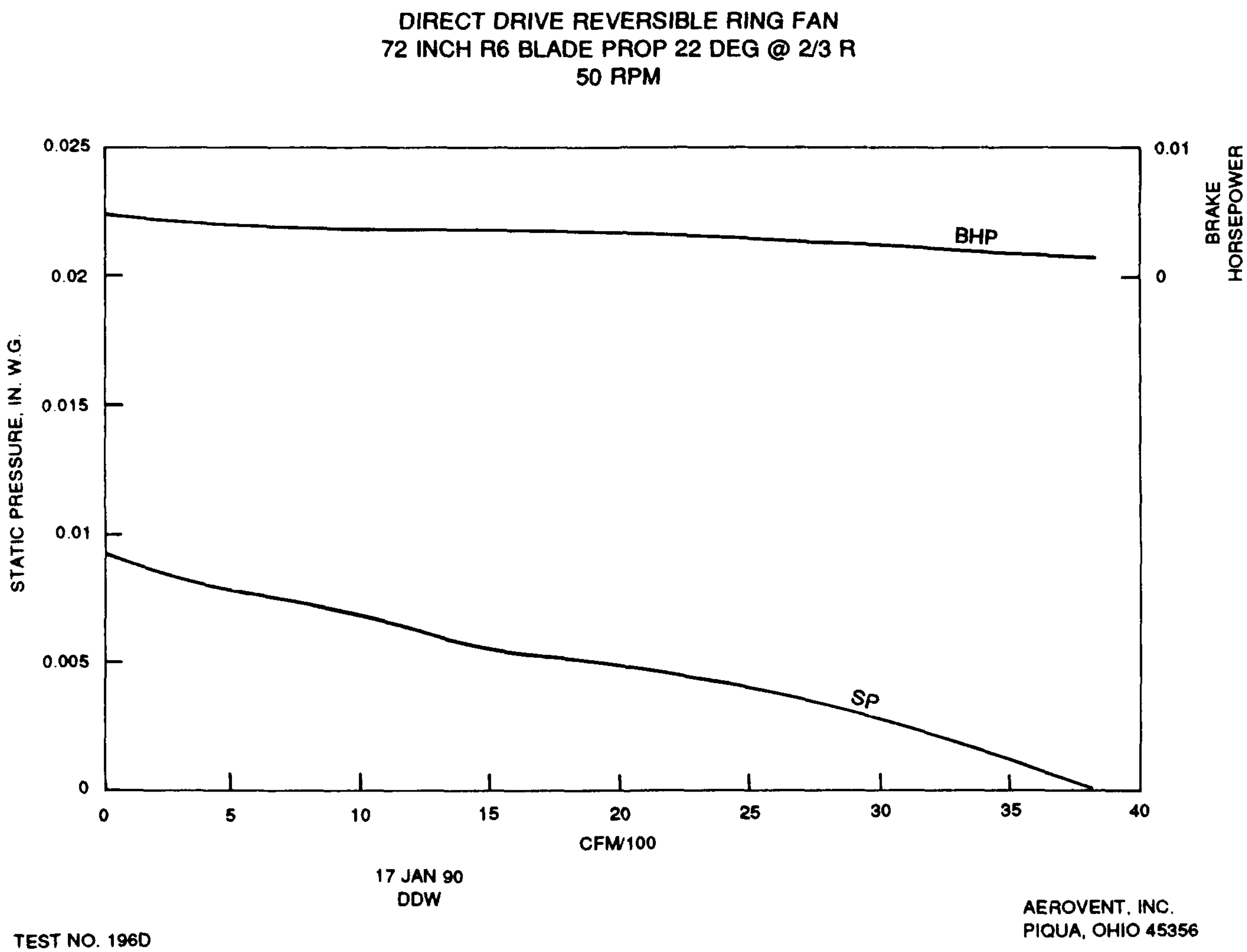

Figure A1. Propeller performance curves

Therefore,

$$P_2 = 0.42 \text{ hp (or } 0.31 \text{ kw)}$$

9. Using the curves for specific blade pitch settings as provided by the manufacturer (Figure A1) and the information above, the same propeller at different blade pitch settings has the following performance at 35 rpm:

Blade Pitch deg	Flow Rate m^3/sec	Velocity m/sec	Blade Power kw
22	1.19	0.45	0.31
30	1.95	0.74	0.67
32	2.12	0.80	0.82

10. To determine the approximate flow rate necessary for whole lake destratification, the normal volume of the anoxic hypolimnion should be used. From the author's previous experience at Ham's Lake, the required flow rate for destratification of the lake is about equal to pumping the volume of the hypolimnion every 8 days. With a volume of the hypolimnion of approximately 6×10^6 m^3 and a recommended destratification time of 8 days, a flow rate of 8.7 m^3/sec is required.

$$6 \times 10^6 \text{ m}^3 \times \frac{1}{8 \text{ days}} \times \frac{1 \text{ day}}{86{,}400 \text{ sec}} = 8.7 \text{ m}^3/\text{sec}$$

11. Using the above performances of a 1.83-m propeller at 35 rpm, 4.4 pumps will be required at a blade angle of 30 deg; 4.1 pumps will be required at 32 deg. The design specifications for four pumps having the 1.83-m propeller at 35 rpm were written. Appendix B provides copies of the actual specifications, parts list, and drawing supplied to contractors for bids and ultimately for construction of the pumps.

Conclusions

12. A detailed discussion of the destratification system is given by Punnett (1988). Conclusions from that report were as follows:

a. The epilimnion was increased (the major objective).

b. The pumps were sufficient for destratifying Beech Fork Lake even though a strong thermal-density difference existed prior to the start of pumping.

c. Mixing occurred throughout the lake, even though the shape of the lake did not appear to be suited to mixing and pumping was conducted at only one location.

d. The water in the vicinity of the dam did not become anoxic. Although at times the overall DO was low, only less than 1 percent of the lake volume became anoxic for a short period.

APPENDIX B: SPECIFICATIONS FOR AXIAL FLOW PUMPS

General Description

1. These specifications are for the construction of four axial flow (fan-type) pumps. Each pump consists of a flotation raft and support frame, electric motor, right-angle drive gearbox, shaft and bearings, and a 6-ft-diam fan (propeller). The motor and gearbox are mounted on the raft. The support frame, suspended below the raft, is used to stabilize the shaft and propeller as well as provide a base when the pump is on dry land. A sketch is provided as Figure B1; a generalized parts list is given in Table B1.

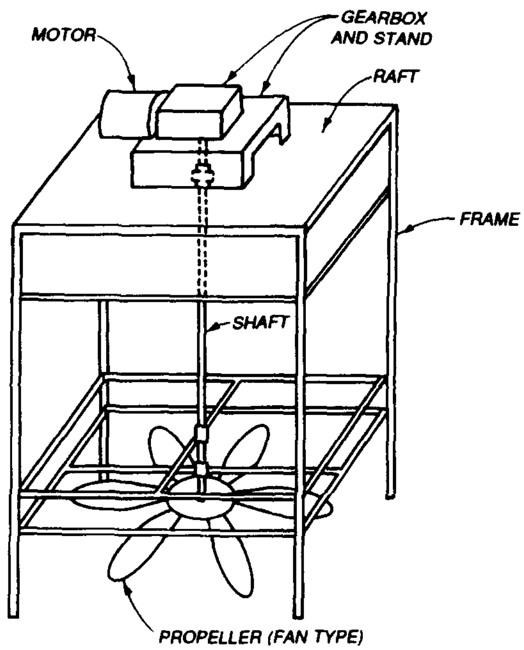

Figure B1. Axial flow pump (shown without optional shroud)

Technical Description

2. The raft shall be constructed of pressure-treated wood (approved by US Environmental Protection Agency for water use) or a steel hermetic container, with at least a 6.5-ft square deck. The raft shall be supported with sufficient flotation to give the pump a freeboard of about 18 in. above the waterline. The flotation material, if used, shall be gas and oil proof, and enclosed for protection from waterfowl. The frame shall be constructed of

metal and painted with high-performance epoxy paint. The electric motor shall be a 3-hp, 3-phase, 240-volt, TEFC (total enclosed fan cooled) motor. The motor shall be mounted directly on the gearbox. The right-angle gearbox shall have a 50:1 reduction and be rated for continuous operation. The shaft shall be made of 2-in.-diam, cold-rolled steel (about 8 ft long), and painted with a high-performance epoxy paint. The coupler that connects the gearbox output shaft to the propeller shaft can be either a steel sleeve type or a flexible, chain-type coupler. The propeller shall be six-bladed, 6 ft in diameter, with a variable pitch (e.g. Model 72R6xx from Aerovent, Inc., Piqua, OH). The propeller shall be suspended about 6 ft below the water surface and sufficiently supported with guide and thrust bearings to be stable under full speed (about 35 rpm). The pump will be used in a lake and subject to weather; therefore, the construction and all components shall be compatible with an adverse environment.

Table B1

Generalized Parts List

Part	Description
Frame	Metal, designed to stand on dry land as well as provide a stable support for the shaft and propeller while operating. The metal should be painted with a high-performance epoxy paint unless made of corrosion-resistant metal.
Flotation	Hermetic container or styrofoam (or equivalent) that is gas and oil resistant and enclosed for protection from waterfowl.
Motor	3-hp, 3-phase, 240-volt, weatherproof, continuous operation.
Gearbox	Right-angle drive (horizontal input, downward output), 5-hp input, weatherproof, continuous operation, 50:1 reduction, motor-mount flange and coupling.
Coupler	Steel sleeve or flexible, chain-type.
Shaft	2-in.-diam, about 8 ft long, cold-rolled steel, high-performance epoxy coating (painted).
Bearings	For 2-in.-diam shaft, submersible, with thrust bearings if needed.
Propeller	Fan-type, 6-ft-diam, six-bladed, adjustable pitch (e.g. Model 72R6xx from Aerovent, Inc., Piqua, OH). Shroud optional.